

When a somewhat weak current is passing between the knobs of a Becker-Voss electro-induction machine, its passage can be altogether stopped by simply blowing across the path of the current. The handle is turned in vain; and even when the blowing has ceased, a short time is required before the current is able to pursue its old path. When the instrument has been warmed, and the current becomes stronger, the blowing, although now unable to stop the current altogether, drives it into irregularly curved paths, which are determined by the force exerted. I do not remember to have seen the experiment mentioned in any book. It is as curious as it is simple.

We now see why the air requires to be at rest for the weak current to force a passage through it, and to keep that passage open for the succeeding sparks to follow; while the stronger current leaps from point to point, as though in pursuit of the warmed and opened passage which has been driven by the wind out of its former position.

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All Hallow's College, Dublin, April 15

### CYCLONES<sup>1</sup>

SINCE it first became known that a considerable proportion of the storms which visit this part of Europe come from the middle and northern parts of North America, the meteorology of that country has been invested with a peculiar and increasing interest for the inhabitants of Western Europe, and though, according to Hoffmeyer, the chance that a depression in the United States will subsequently cause a storm somewhere in our own islands is only one in four, it is a ratio quite substantial enough to make us regard with attention warnings such as those transmitted to us through the medium of the *New York Herald*.

While America is thus from her enormous size and westerly position enabled to act the part of our weather prophetess, she bids fair in addition to leave us far behind in the more theoretical branches of weather-science, and though to admit this may be somewhat wounding to our national *amour propre*, it is nevertheless an idea which is openly entertained by some of our leading meteorologists. For our comfort it may be reasonably ascribed, in part at least, to our small size and unfavourable geographical position having afforded but little encouragement to really able men to devote their attention to a science whose operations are conducted on a scale compared with which our area of observation is indeed microscopic, so that until within quite recent times the succession of fair and foul weather in these islands was regarded merely as a series of irregular, eccentric, and totally unpredictable changes. The work before us, entitled "Methods and Results," by Prof. William Ferrel, of the American Coast Survey, and prepared for the use of the coast pilot, forms the second part of a series of meteorological researches undertaken by the author, which comprise an elaborate theoretical investigation into the general and local mechanics of the atmosphere. In Part I., which appeared in 1877, the general motions of the atmosphere are more particularly dealt with, and conclusions are arrived at which have appeared in part in the *Mathematical Monthly* for 1860 and the *American Journal* for November, 1874.<sup>2</sup>

In both these publications the author lays great stress upon the important part played by the deflecting force to the right of its path, to which a current of air is subjected by virtue of the earth's rotation in whatever direction it may be blowing. This deflecting force is measured by the acceleration  $2n \cos \psi$ , where  $n$  represents the angular velocity of terrestrial rotation, and  $\psi$  is the co-latitude (see NATURE, vol. v. p. 384).

With the assistance of this element he theoretically deduces in Part I. the general motions of the atmosphere, which agree with what is known from observation. He

<sup>1</sup> "Methods and Results of Meteorological Researches for the use of the Coast Pilot." Part II.—On Cyclones, Waterspouts, and Tornadoes. By William Ferrel. (Washington, 1880.)

<sup>2</sup> "Relation between the Barometric Gradient and the Velocity of the Wind," by W. Ferrel, Assistant U.S. Coast Survey.

also makes considerable use of this same principle, which he was the first to enunciate correctly, when dealing with the theory of cyclones in Part II. As we propose just now to confine our attention to Part II., which treats mainly of cyclones, we shall not refer to Part I. except incidentally. Part II. is sub-divided into three chapters, the first of which deals with the mechanical theory of cyclones, and deductions therefrom. In Chapter II. the results of the theory are compared with those of observation, and Chapter III. treats of tornadoes, hailstorms, and waterspouts. The chief elements considered in the theory of cyclones are (1) the earth's rotation, (2) the gyrotory velocity round the low centre, (3) the friction, (4) the inertia, and (5) the temperature and humidity of the air.

These elements are all discussed in turn, and many important conclusions drawn from the resulting equations. Some of these conclusions have already been either directly deduced by the employment of analogous methods, or inductively inferred from an examination of data, by Guldberg and Mohn, Colding, Peslin, Sprung,<sup>1</sup> Clement Ley, Hildebrandsson, Meldrum, Loomis, and Toynbee. Some however are quite new, especially those which are derived from a consideration of the temperature term.

The general theory of the cyclone, according to Ferrel, may be briefly stated thus:—

If from any initial cause interchanging motions are set up between the air in a certain district and another surrounding it, the air in the first district tends to gyrate round its centre by virtue of the deflective force of the earth's rotation, and in the same direction as that of the component of terrestrial rotation, which acts in the plane of its horizon. In the northern hemisphere this would mean gyration contrary to watch-hands, and in the southern hemisphere gyration with watch-hands. In the outer district the gyrations of the air, by the principle of the preservation of areas (or moments), are contrary to those of the interior district. These two systems of contrary gyrations tend to draw the air from the centre of the inner district and the exterior limit of the outer district, and heap it up in the place where the gyrotory velocity vanishes and changes sign, thus causing a maximum barometric pressure there, with corresponding minima at the centre and outer limit respectively.

In addition to this, when the gyrations have once commenced they give rise to a centrifugal force which tends to drive the air still more from the centre of the inner district, and so increase the barometric depression there; but which in the outer district, partly owing to its distance from the centre, and partly to the small velocity of the gyrations, has but little effect on the distribution of pressure. The gyrations, especially near the centre and exterior limit, would be very rapid, were it not for the friction between the air and the earth's surface, which retards the motion, but does not entirely prevent it, since, as the author very pointedly remarks, "without some such motion frictional resistance would not be brought into action." So far we have only considered the gyrotory component of motion, and as in the imaginary case of no friction, this would be the only kind of motion, the gyrations might then be entirely circular. When, however, as actually happens in the atmosphere, friction acts, a radical component becomes necessary, since the deflecting force is now partly employed in counteracting the frictional resistance to the gyrations, and the magnitude of this radial component (on which depends the inclination of the wind to the isobar), varies *ceteris paribus* directly with the amount of friction.<sup>2</sup> As a result of the two

<sup>1</sup> "Die Trägheits-curven auf rotirenden Oberflächen," *Zeitschrift für Meteorologie*, Band xv., January Heft, 1880.

<sup>2</sup> This result is best seen in the following expression for the angle of

inclination of the wind to the isobar  $\tan i = \frac{f}{2(n \cos \psi + \frac{s \cos i}{r})}$ , where  $f$

is the coefficient of friction,  $s$  the velocity of the wind, and  $r$  the distance from the low centre.

tendencies—gyration and inflow, or outflow according as the air is in the interior or exterior part—the air near the surface takes a middle course, and flows spirally around and toward the centre from the zone of maximum pressure on the one side, and on the other in a contrary spiral outwards from the centre to the outer limit of the anticyclone.

It is important to observe that the author explains the accumulation of air with its maximum at the dividing line between the interior and exterior districts (cyclone and anticyclone, as they are termed elsewhere throughout this work) as “due at the start mostly to the gyrations in the upper part of the atmosphere,” which, being less influenced by friction, are in consequence more circular than those below; the pressure from this accumulation tending to force the air near the earth's surface out from beneath it on the one side toward the centre of the cyclone, and on the other toward the outer limit of the anticyclone.

The difference of pressures or gradient between the regions of high and low pressure in a cyclone, is thus shown to be, not so much the cause of the wind, as the mechanical result of the deflecting force of the earth's rotation and the centrifugal force engendered by the gyrations.

It should, however, be borne in mind, that the forces just mentioned, are by no means to be regarded as causing the cyclone in the sense of being independent sources of energy. They can only arise in consequence of some initial motion of the air, which must itself be due to a small difference of pressure, and unless such primary disturbing cause be continually maintained by external influences, the entire system of motion will shortly come to rest.

The preceding view of cyclone generation has already made some way since Ferrel first enunciated its leading characteristics in his previous writings. It lies midway between what is sometimes called the in-blowing or ascension-current theory of Reye and Espy, which regards the central depression as the main cause of the wind, and that held by Thom, Meldrum, Willson, and Loomis, according to which the central depression is mainly due to the centrifugal force generated by two pre-existing currents passing one another in opposite directions. A third theory, held by Blanford and Eliot, and evolved chiefly from a study of the cyclones in the Bay of Bengal, makes the condensation of vapour the primary cause of disturbance, but allows the greater part of the subsequent depression of the barometer to be due to the causes adduced by Ferrel. This latter theory, in fact, only differs from that put forward by the author in the part played by condensation of vapour in giving rise to the initial motion of the air, which Ferrel considers to be considerably less than that exercised by a difference of temperature. Among the conclusions arrived at by the author, and which are generally confirmed by the results of observation, may be noticed the following; but these, it must be remarked, are only strictly true for a regular, symmetrical, and stationary cyclone:—

(a) “The wind inclines towards the centre from the direction of the tangent, and the amount of inclination is nearly in proportion to the friction (mainly of the air against the earth's surface).”

(b) “The inclination diminishes with the altitude, and therefore at some distance from the earth's surface the gyrations are more circular than near it.”

(c) “Toward the centre of a cyclone, where the gyratory velocity is greater, the inclination is less, and therefore the path more nearly circular.”

(d) “The inclination increases with decrease of latitude, attaining its greatest value at the equator, where the air should flow directly towards or from the centre, and there should be no gyrations.”

(e) “As the motion of the air below in cyclones is toward the centre, in the upper regions of the atmosphere it must

be nearly circular, but inclined to the tangent a little from the centre.”<sup>1</sup>

Inertia comes into play where a cyclone is increasing or diminishing in violence, and its effect is to increase the inclination in the former case and diminish it in the latter, but in general the amount is found to be insignificant.

It was stated in the above brief sketch of the theory, that outside the annulus of high pressure surrounding a cyclone the air should move outwards anticyclonically. Ferrel subsequently puts the matter thus: “Every cyclone is accompanied by a corresponding anticyclone, and the former cannot exist without the latter.”

The words cyclone and anticyclone are here used quite apart from the question of barometric pressure, and simply mean districts in which the motion of the air is spirally in towards the centre, or out from the centre respectively. Guldberg and Mohn likewise adopt this definition, which is obviously far more scientific than the too common habit of referring to them as regions of low and high pressure.

Mr. Ferrel, however, differs from all previous investigators in thus linking together the cyclone and anticyclone as mutually dependent parts of the same phenomenon. They have hitherto been treated separately, at least in practice, and though the author's conclusion sounds like a simplification, because it makes one out of two, we scarcely think he has proved the converse to his proposition, viz. that every anticyclone is accompanied by a corresponding cyclone, and cannot exist without it.

For example, in the case of such an anticyclone as every winter forms over Central Asia it would be difficult to point out exactly its corresponding cyclone or cyclones, though it is possible, as the author says, that it may be partly due to the overlapping of the anticyclones, which should surround the permanent North Atlantic and Pacific cyclones at this season.

The relation between the barometric gradient and the velocity of the wind in a symmetrical cyclone is given by the following equation:—

$$G = \frac{1076 \cdot 4 (2n \cos \psi + \nu) s}{\cos i (1 + \cdot 004 t)} \frac{P}{P^1},$$

where  $\nu = \frac{s \cos i}{r}$ , and  $G$  is the gradient in millimetres

per sixty geographical miles,  $s$  the velocity of the wind in metres per second,  $n$  the earth's angular velocity of rotation per second,  $\psi$  the co-latitude,  $i$  the inclination of the path of the wind to the isobar,  $P$  the barometric pressure at the given elevation and at the earth's surface respectively,  $t$  the temperature in degrees Centigrade, and  $r$  the distance from the low centre in kilometres. Where the gradient is given, the velocity of the wind can be conveniently found from the equation

$$S = -\frac{1}{2} a \pm \sqrt{\frac{1}{4} a^2 + b G},$$

where, if the ordinary English units of space and time are used, viz. a mile and an hour, and the gradient is expressed in inches per sixty geographical miles, we have—

$$\begin{cases} a = \frac{0 \cdot 52505 r \cos \psi}{\cos i} \\ b = \frac{r (1 + \cdot 004 t) P}{\cdot 005262 P^1} \end{cases}$$

The equation for the gradient in terms of the wind's velocity is substantially the same as that already given by the author in *Silliman's Journal* for 1874, with the exception of the temperature correction, which was there simply referred to in the text.

As the whole question of the author's formula for the gradient has been thoroughly ventilated in his previous

<sup>1</sup> This conclusion only applies to districts within a moderate distance from the centre. At great distances from the centre the radial component predominates, and the air flows nearly directly towards the centre below, and from it above.

works and in the *Zeitschrift für Meteorologie* (Band x.), we need not notice it here except to point out that, assuming the correctness of the formula, the gradient, *ceteris paribus*, should vary (1) directly with the latitude, (2) inversely with the distance from the centre, (3) inversely as the temperature, (4) directly with the amount of inclination.

The foregoing results have all been obtained without considering the term depending on temperature and humidity, and which expresses the effect of the disturbing force necessary to start and maintain the interchanging motions between the interior and exterior portions of the air over a given area. That such a disturbing function is necessary, is evident both from preliminary considerations, and also from the form of the general equations of motion, since they would otherwise be satisfied by the conditions for a state of *rest*. The author enunciates this principle in Part I. Chap. III. where he says: "*There can be no winds then without a disturbance of the static equilibrium by means of a difference of temperature or of aqueous vapour in different parts of the atmosphere.*" And it is important to bear it in mind, if only because we are too often apt to overlook it in the multitude of secondary causes brought to light by a study of atmospheric mechanics. A consideration of this term, in which temperature and humidity are treated jointly, and the former is *assumed* to vary with the distance from the centre, leads to the remarkable conclusion that there are two species of cyclones, one with relatively *warm* centres, the more common case, and the other with relatively *cold* ones.

These cyclones differ specifically from each other chiefly in the way in which the pressure is distributed and the gyrations directed at different altitudes.

In a cyclone with a relatively warm centre the air at the earth's surface moves in a cyclonic spiral round and towards the centre, but as we ascend the gyratory velocity diminishes with the altitude, and the annulus of high pressure approaches the centre, until at a very high elevation the highest pressure of that stratum might even be at the centre, and the air gyrate anticyclonically from it over the whole area at that level. In brief, the cyclonic area becomes smaller, and the anticyclonic larger, as we ascend.

In a cyclone with a cold centre the reverse occurs. At the surface of the earth the initial tendency of the air is to move outwards, and this may be so strong near the surface that there may be only anticyclonic gyrations at this level, with the maximum pressure of the *lowest* stratum at the centre. As we ascend, however, the gyrations round the centre become more and more cyclonic, while the annulus of maximum pressure gradually retreats further and further from it.

There is, besides, according to the theory, an *ascending* motion of the air in the interior part of a warm-centred cyclone, and a descending motion in the exterior part, both generally *small* in comparison with the horizontal motions toward and from the centre. In the case of a cold-centred cyclone these motions are reversed.

Now as a barometer at the earth's surface records simply the integrated effect of what happens in all the strata up to the top of the atmosphere, this might obviously vary in the *same* way for both kinds of cyclones, and so tell us absolutely nothing of such remarkably diverse conditions prevailing at higher altitudes. The behaviour of the air in the warm centred cyclone is what we are accustomed to observe in the case of *most* cyclones, and as they are as often found with relatively *cold* centres as with *warm* ones, the former occurring more frequently in *summer* and the latter in *winter*, it is difficult to understand why the characteristics of the cold-centred cyclone have never yet been found to prevail, at least in moving cyclones. The author indeed offers an explanation of this circumstance, and endeavours also to account for the

absence of stationary cold-centred cyclones in regions like Central and Eastern Asia and North America in winter, where the temperature gradient would be remarkably favourable to their production. The fact, however, that in the centres of these regions at this season there is not only no cyclonic tendency of the winds or depression of the barometer, but, on the contrary, a pressure greatly above the normal, seems strangely at variance with what we should expect according to the theory of the cold-centred cyclone, and is hardly satisfactorily explained away as the result of the irregularity and size of the area, combined with the excessive *cold*, which latter is supposed to increase the density and pressure more than the cyclonic tendency diminishes them. The only two cases of cyclones with cold centres which the author seems able to find are the two general wind systems of the northern and southern hemispheres respectively, which "are simply two great cyclonic systems with a cold centre, having the cold poles of the earth for their centres. The motion of the air eastward around and toward the poles in the middle latitudes, giving rise in those latitudes to the normal south-west winds in the northern, and north-west winds in the southern hemisphere, form the cyclones, and the trade-wind region the corresponding anticyclones, with the equatorial calm-belt for the common limit of the two systems. The tropical calm belt and corresponding maxima of barometric pressure near the parallels of 30°, correspond to the similar calm and dividing line between the cyclone and anticyclone in the ordinary and smaller cyclonic systems."

The primary cause of cyclones, according to Ferrel, is a *horizontal temperature gradient*, so that if a portion of the atmosphere is heated or cooled more than the surrounding parts, and the isotherms are approximately circular, we have the initial conditions for a cyclone; but after the disturbances due to such primary causes have set in, secondary causes depending on loss of heat by expansion in ascent, and gain of heat by compression in descent, as well as retardation of cooling where aqueous vapour is being condensed, come into play, which *on the whole* tend to counteract the initial motions.

The condition of the atmosphere *vertically* with respect to temperature and humidity, is thus of great importance in regard to the duration of a cyclone when it has once started.

The author investigates this point at some length, and works out the conditions for cyclone generation in quite a novel manner, from a consideration of both vertical and horizontal temperature gradients. Generally speaking, the condition most favourable to the maintenance of an ordinary cyclone is that the vertical temperature decrement in the interior should be less than in the surrounding regions. This condition is found to be more easily sustained where the air is charged with aqueous vapour, since under these circumstances it cools less rapidly in ascending than when dry. He further points out that where the decrement of temperature in the interior is less than outside, especially when this condition occurs throughout the entire atmosphere, a cyclone may arise without any horizontal temperature gradient (provided only a small instantaneous impulse be given), and that such a state of *unstable equilibrium* more readily occurs when the air is warm and saturated with vapour. While, however, he thus admits the important rôle played by vapour in maintaining cyclonic action when once started, he distinctly denies its claim to be considered "*either a primary or principal cause of cyclones.*"

As these islands in all probability seldom, if ever, form the birthplace of a cyclone, but we are rather accustomed to experience them either fully developed or else in the condition of being "filled up," the circumstances which attend their generation do not practically very much concern us. Still it must not be overlooked that conditions which would tend to create and maintain a cyclone in our midst, must of necessity tend to augment the

violence of a storm arriving on our coasts, so that if meteorology, or that branch of it termed weather forecasting, is ever to become an exact science, we must endeavour to find out, by captive balloons or otherwise, what can never be determined by registration at the earth's surface alone, viz. the condition of the atmosphere *vertically* as regards temperature and humidity.

The author concludes his theoretical investigation into the mechanics of cyclones by a discussion of the causes of their motion over the earth's surface. He first of all shows that every cyclone possesses an inherent force tending to urge it towards the pole of the hemisphere in which it has been formed. This follows immediately from the fact that the deflecting force due to the earth's rotation varies with the cosine of the colatitude, and is therefore greater on the polar than on the equatorial side of a cyclone, a residual poleward component of force being thus brought to bear upon every portion of the cyclone. In addition to this, a cyclone, as soon as it is generated, must partake of the general motions of the atmosphere, which the author more especially deals with in his "Meteorological Researches," Part I., to which we have already made allusion; and since the general motions of the atmosphere are there considered to form two great cyclonic systems round the poles, all ordinary cyclones are simply cyclones within a cyclone, so that their general motion of translation is partly the result of the actual motion of the air in these large and perpetual, though perpetually changing, cyclones, and partly that of their inherent tendency to *press polewards*.

For example, as the author says, "in the trade-wind latitudes the wind at the earth's surface is westward . . . and hence the cyclones in these latitudes are carried westward, . . . and having a tendency towards the Pole, the resultant of the two is a westward motion, inclined a little towards the poles, or in the northern hemisphere a motion about west-north-west. After having arrived at the parallel of 30° or 35° in the tropical calm-belt, where there is no westward motion, the progressive motion is a Polar one mostly, but after progressing still nearer the Pole, into the middle and higher latitudes, the general eastward motion of the atmosphere here, which is great in the upper regions, carries now the cyclone toward the east, and the direction of the progressive motion, which is usually about east-north-east, is the resultant of this eastward motion and the motion round the Pole. All well-developed cyclones, therefore, having their origin near the equator, have mostly a progressive motion represented by a curve somewhat in the form of a parabola, having its vertex in the tropical calm belt at the parallel of 30° or 35°."

It is moreover shown that the general motions of the atmosphere must not only cause the cyclone to travel more or less with them, but also affect the inclination of the wind to the isobars, decreasing it in the front, and increasing it in the rear part.

With regard to further modifying causes, the author favours the views of Clement Ley regarding the effect of the distribution of aqueous vapour in determining the direction in which a cyclone propagates itself.

He does not indeed attempt to explain how they sometimes wander off on an entirely unlooked-for course, or else remain stationary for some considerable period; otherwise he might claim to have at least attempted a solution of the entire problem on which weather science depends. Clement Ley himself, in his admirable little work,<sup>1</sup> recently published by authority of the Meteorological Council, tells us that the reason why the course of a cyclone cannot be exactly foretold is because "in the first place the causes which determine the course of depressions are not fully known; in the second, place so far

as they are known, it is certain that the course of depressions is generally related to the distribution of pressure over a very large area." In fine before we know how the small cyclones are going to behave, we must in every case know the *form* of the larger cyclones round whose centres they travel.

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(To be continued.)

#### THE GIZZARD-CONTENTS OF SOME OCEANIC BIRDS

THE following results of the examination of the gizzards of twenty sea-birds, which were caught by the officers of this ship in the South Atlantic and Southern Indian Oceans during the last quarter of 1881, may be of interest to some of the readers of NATURE.

With one exception all the birds belonged to the Petrel family—the Procellariidæ—and fifteen of them were of the well-known species—the Cape-pigeon or Cape-petrel (*Daption capensis*). The most frequent of the gizzard-contents of these twenty birds were the mandibles of a cephalopod, which were found in eighteen instances; the otoliths of some small osseous fishes occurred in five instances; and some curious stony masses, varying in weight from half a grain to five grains, were obtained also in five instances. The other substances, which were observed less frequently, were the vertebræ of a fish, feathers, Velellæ, the horny rings probably of some crustacean, and a small hard seed.

With reference to the seed just mentioned, I should observe that it was taken from the gizzard of a Cape-pigeon, about 550 miles to the east of Tristan d'Acunha, in the South Atlantic. The wide range of this species of petrel is well known; we ourselves first observed this bird rather to the southward of the island of Trinidad, which lies about 600 miles off the coast of Brazil; and thence we traced it as far as the island of Amsterdam, in the southern portion of the Indian Ocean. From our own observation, therefore, it is quite possible that a seed might be transported from Trinidad to Amsterdam, notwithstanding that these islands are from five to six thousand miles apart; and Mr. Mosely's surmise (*vide* a footnote in Mr. Wallace's "Island Life," p. 250) that various species of Procellaria and Puffinus may have played a great part in the distribution of plants, and may to some degree explain the similarity in the mountain floras of widely distant islands, would appear to receive some support from the single instance of this seed. With regard to the kind of plants to which the seed belongs, Mr. Moore, director of the Botanic Gardens, Sydney, kindly informed me that it possessed no character sufficiently distinctive to enable him to decide as to its probable source.

The stony masses found in the gizzards of five of the birds, all of which were caught in the South Atlantic, were of two kinds: one of the masses was of a dark colour and homogeneous texture, and rather porous; when heated it gave off black fumes with a smell of burnt organic matter, and was fusible with soda into a black glass; the other masses had the appearance of greasy quartz, scratching glass with ease; but when heated in a closed tube they blackened and evolved black fumes with a powerful odour of burnt animal matter; after the incineration they became white, and with the blowpipe were fused into a white glass after the addition of soda; no effervescence was exhibited on the application of an acid. The behaviour of these masses under heat is very similar to that described by Mr. Darwin in his "Geological Observations," in the case of a stony incrustation on St. Paul's Rocks, deposited, as he considered, from water draining through birds' dung.

H. B. GUPPY  
H.M.S. *Lark*, Auckland, February 28

<sup>1</sup> "Aids to the Study and Forecast of the Weather," by W. Clement Ley, M.A., 1880.